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# TIMBER CRUISING ON AERIAL PHOTOS

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## INTRODUCTION

Aerial photographs can provide foresters, landowners, and timber operators with the basis for one of the fastest and least expensive methods of timber estimating. A pulp company, for example, faced with the necessity of expanding its holdings, may find photo-reconnaissance surveys a cheap yet adequate method of locating desirable tracts. Timber managers who need an over-all cutting plan, yet are unable to finance intensive ground surveys far in advance of woods operations, will appreciate its economy. And professional foresters responsible for immediate estimates of timber volume on areas where field work is difficult and time-consuming should find photo cruising useful.

Where the allowable error is at least 10 percent and where such details as volume by species or diameter class may be omitted, air photos without ground work can often furnish the necessary data. Research now in progress will test methods of adjusting aerial volumes for cull and other local variations and will test procedures for distributing those volumes by species, diameter, or other classes not directly interpreted from photos.

This publication describes a method of aerial estimating and discusses its development, accuracy, and limitations.

### Development of Aerial Estimating

Basically, a timber volume estimate is made by multiplying an average per-acre volume by the number of acres in the stand. Traditionally, maps showing the various forest types are drawn to stratify the area and to reduce the volume variation of the plots in any per-acre average. The problem then becomes one of making a volume estimate for each forest type and adding them up to get an estimate for the stand.

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<sup>1/</sup> The authors gratefully acknowledge the assistance of F. Dean Brunson, O. Kieth Hutchison, and Kenneth L. Quigley in gathering and interpreting data and in developing the ideas presented in this manuscript.

About 30 years ago enterprising foresters joined a few aerial photos and used this crude mosaic in the field as a superior form of base sheet on which to sketch their forest type-map. Later, a few foresters became more familiar with aerial photos and realized that by studying contact prints under a stereoscope they could draw many type-lines on the photos without field work.

At the same time, engineers and other foresters were developing instruments and procedures for transferring type-lines from these contact prints to the precise base sheets used in a final map. By simply field-checking the type-lines drawn on the photos and adding types visible in the field but not easily recognized on photos, foresters were able to produce superior type-maps with greater detail at much lower cost.

But statisticians and some early cruisers both in Europe and in this country reasoned that mapping the entire forest stand was not necessary for an accurate cruise. It was obvious, they said, that if a mapped area were completely covered with 1-acre plots and each plot were given the classification of the type in which it lay, a count of the plots in each type would exactly equal the area in each type. Furthermore, it could be proved statistically that a small random sample of acre plots would result in substantially the same proportions. Based on this reasoning, they suggested a mere classification of sample plots, the number to be determined by the accuracy desired. Proportions based on these samples could then be used to distribute the total area by the classes recognized.

The satisfactory results obtained by the line-plot method,<sup>2/</sup> a modification on this form of sampling, during its wide use by the Forest Survey clearly indicated that a forest type-map was not a necessary part of timber estimating.

As aerial photos were gradually integrated into type-mapping procedure, foresters familiar with the line-plot method toyed with the possibility of locating the plots on contact prints and classifying them by their photo characteristics. If this could be done with reasonable accuracy, they argued, area measurements could be based on the photos and completed without the delay or expense of either type-mapping or field-plot classification.

Throughout this long period of evolution, although area measurements were based on field maps, on sample plots, and eventually on aerial photographs, average per-acre volumes were always obtained from field measurements. Total volumes, the product of these averages and area measurements, were distributed into species and diameter classes by proportions based on field data. Such methods,

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<sup>2/</sup> G. H. Lentz. The Forest Survey in the bottomland hardwoods of the Mississippi delta. Jour. Forestry 29:1046-1055. 1931.

regardless of the degree to which they use photos in mapping or classification should be considered field procedure; since volumes are determined from field measurements, the emphasis remains on that phase and the procedures must be looked upon as mere refinements of an old and relatively inefficient inventory system.

By contrast, in aerial estimating the emphasis is on interpreting and measuring aerial photos. Stands are classified by stereo-interpretation of contact prints, class areas are measured on photos or photo-maps, and per-acre volumes are estimated from photo measurements and aerial volume tables. It is then possible to compile total gross volumes from the study of aerial photos alone.

In practice these gross photo volumes may be reduced to net volumes, and these net volumes may be distributed into classes unrecognizable on aerial photos by means of factors determined from a few field plots. This limited field work does not change the basic concept of an aerial survey and on many reconnaissance-type surveys may be unnecessary.

Although much of the aerial survey method has been a part of Forest Survey procedure since 1946, the lack of suitable aerial volume tables has greatly retarded the growth of true aerial estimating. Our first task, therefore, was to construct usable aerial volume tables.<sup>3/</sup> During the same period, the technique described in this paper was conceived and tested on a number of surveys. It is designed to make maximum use of aerial photographs.

### THE PROCEDURE

The basic procedure will be described under the headings (1) photo and templet preparation, (2) area measurements, (3) plot volume estimates, (4) total volume estimates, and (5) cruise report maps.

#### Photo and Templet Preparation

The scope of this publication does not allow discussion of either the procurement or types of aerial photographs; both have been adequately discussed in many other publications.

After photos covering the tract have been secured, they must first be prepared for use. Normal overlap in contact prints is 60 percent within flight lines and 30 percent between flight lines. The net area--one-half of this overlap--must be outlined on each

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<sup>3/</sup> K. E. Moessner, F. D. Brunson, and C. E. Jensen. Aerial volume tables for hardwood stands in the Central States. Central States Forest Expt. Sta. Tech. Paper 122. May 1951.

print so measurements made on successive prints will not duplicate each other (fig. 1). The part of the tract lying within the net area is then outlined (fig. 2). Boundary lines are normally marked in colored pencil on semimatte prints although colored inks may be used.

A templet is constructed of transparent plastic (fig. 3). Evenly spaced throughout the templet are 1-acre plot circles, the number depending upon the sampling accuracy desired. The center of each plot is marked by a needle hole, and the plots are numbered consecutively throughout the templet. Orienting lines are etched at the edges of the templet to coincide with the fiducial points at the edges of the contact prints.

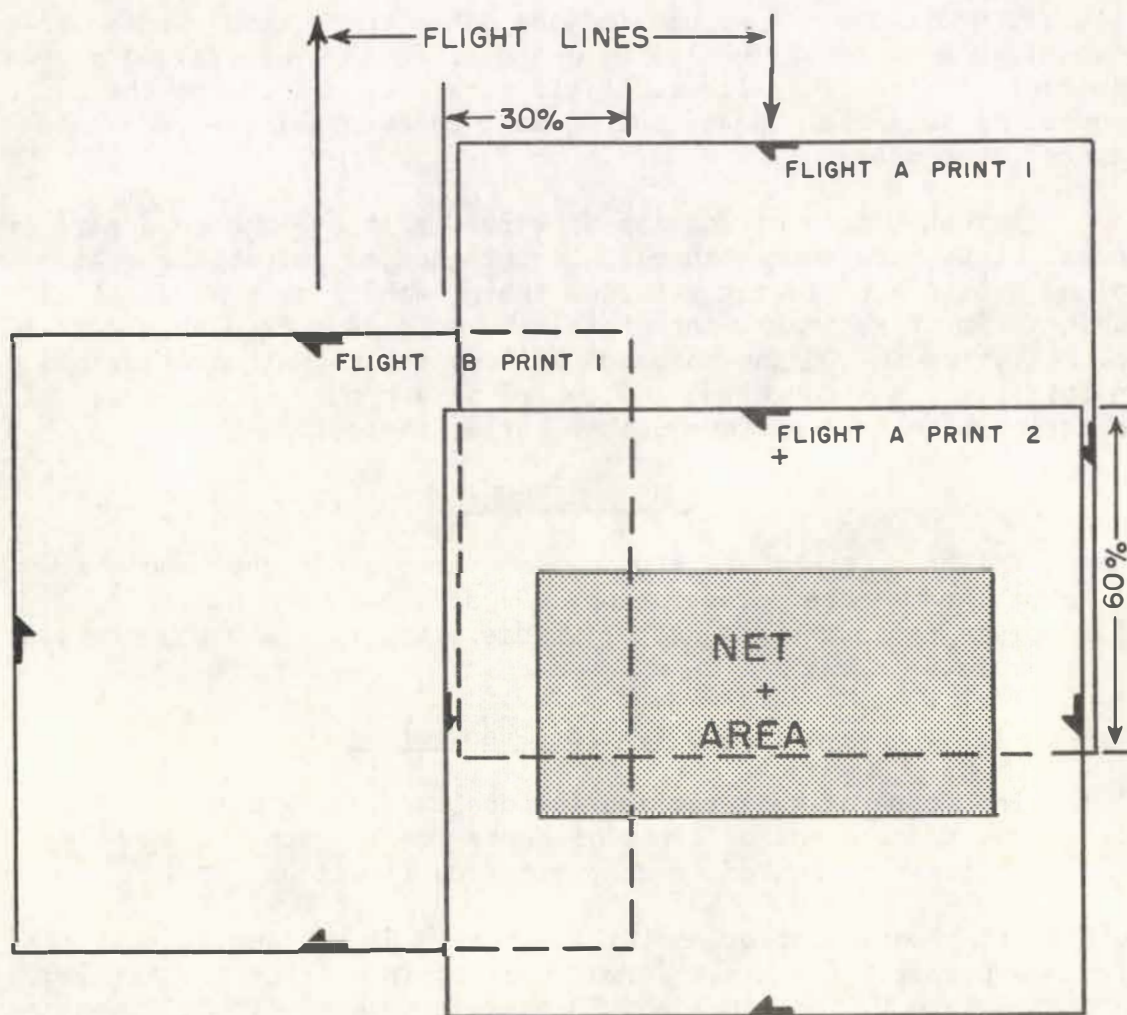


Figure 1.--Net area is outlined as one-half the overlap with adjoining prints.

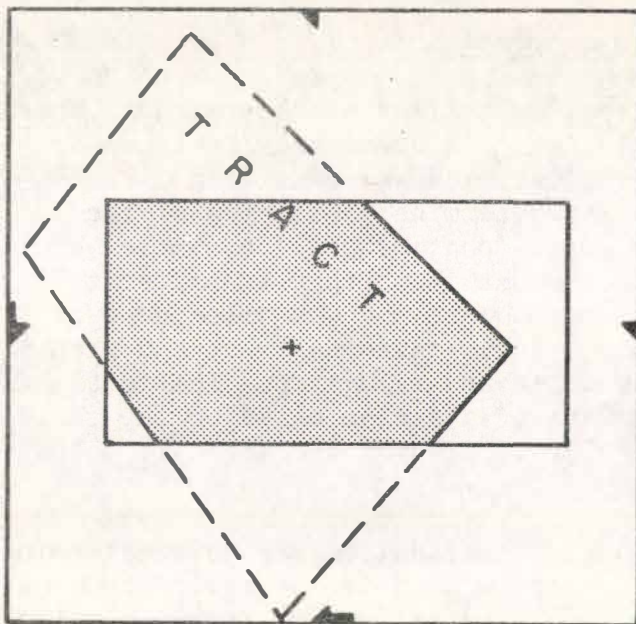


Figure 2.--The part of the tract within the net area is then outlined on each print.

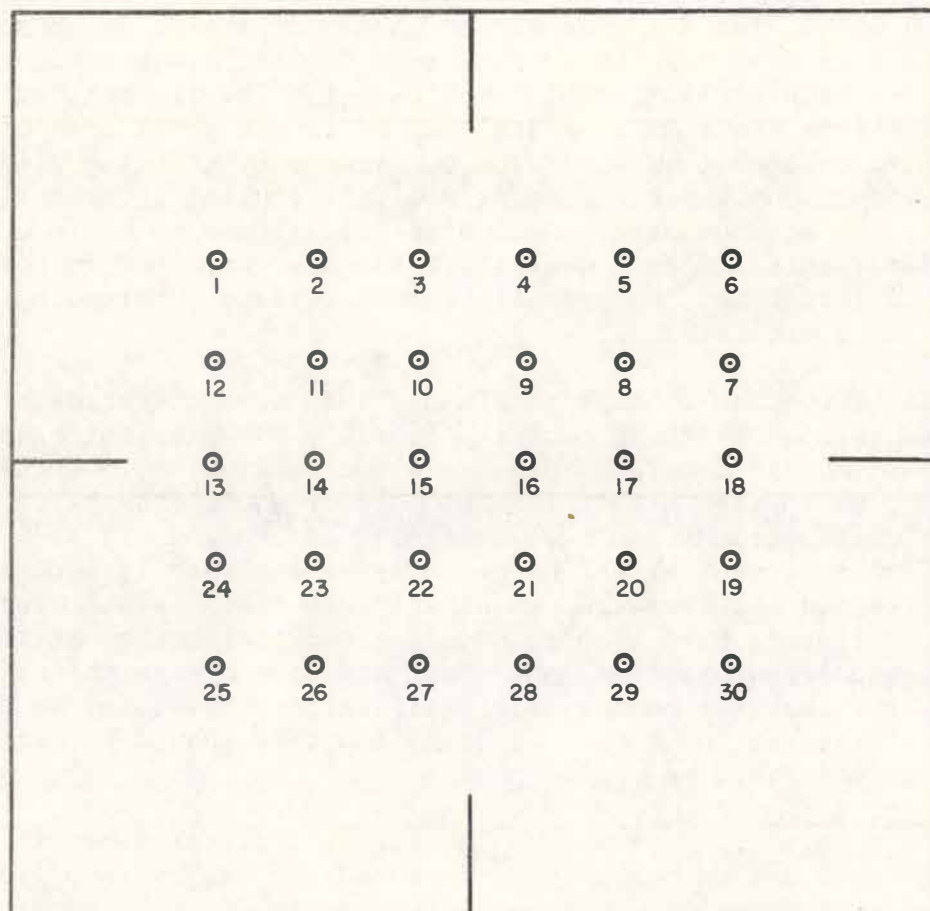


Figure 3.--A templet is constructed on transparent plastic with orienting lines to coincide with the fiducial points of the photos. On it are a predetermined number of evenly spaced 1-acre circles centered over pin-point holes.

### Area Measurements

The gross area of the tract must first be determined. Where the land has been surveyed, this figure will usually be known or can be calculated. In unsurveyed territory or on extremely irregular tracts it may be necessary to determine gross area of the tract by direct measurement on aerial photographs. A simple yet accurate method consists of a dot count in which a transparent templet having 100 or more dots per square inch is oriented over each photo in turn, and the dots lying within the tract and within the net area of the photo are counted and tabulated. The total is then converted to acres by means of a factor based on the scale of the photos. In any case, the gross area of the tract is determined as precisely as possible.

Forest area by the various classifications is next determined. Since many of the classifications to be used can be recognized only in third dimension, the photos should be set up for stereo-viewing with the templet oriented over one photo of the stereo-pair. Each plot lying within the net area of the photo and inside the boundary of the tract is then tallied by classification. This procedure is repeated for each contact print covering a portion of the tract. Proportions from these tallies are applied to the gross area of the tract to distribute the acreage by class. By starting with a precisely computed over-all acreage and distributing it proportionately, the acreage determination is less likely to be in error than if dot counts for each classification are converted to acres directly by factor and the over-all forest acreage obtained by totaling these estimates.

Classification schemes should be based upon characteristics easily recognized on aerial photos. Probably the simplest classification would merely separate forest and nonforest areas. Forest areas might be further stratified into old or young growth, or on the basis of topography, such as upland or bottomland sites.<sup>4/</sup> On infra-red photos, conifer and hardwood types are readily separated. More experienced interpreters can effectively classify stand sizes, such as saw timber, pole timber, seedling and sapling, by estimating total height, crown diameter, and crown coverage on the photos. In any case, the smallest number of classifications necessary to give the desired information should be used, and they should be defined in terms recognizable on aerial photos.

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<sup>4/</sup> "When photos are viewed in stereo, vertical dimensions are exaggerated and topographic differences are easily recognized. Since topography modifies soil and air moisture, it has important bearing on site quality. On photos, cool moist slopes are easily segregated from hot dry ones and ridge and upper slopes from bottoms." Karl E. Moessner. Photo classification on forest sites. Proc. Soc. Amer. Foresters' Meeting. 1948.

The cost of classifying is small, less than one-half cent per plot. The number of plots classified depends upon the statistical accuracy desired (appendix page 22). On areas of 40 acres or less the interpreter may classify almost 100 percent of the area. On larger tracts the number of acre plots will be greater but the proportion of total area examined will be far less.

The method is easy to use. Each acre plot is small enough to be treated as a unit, yet large enough to encompass small holes in the forest. Each has a definite boundary and is classified (typed) on the basis of its own characteristics. And each plot constitutes a separate problem which the interpreter can solve without completing obscure and often meaningless type-lines.

### Plot Volume Estimates

Plot volumes are estimated on a predetermined number (see appendix page 22) of measured 1-acre plots. Plots to be measured for volume estimates are selected mechanically as they are classified. For example, if we expect 100 plots to be tallied in a given classification and estimate 20 will be needed for a reliable volume estimate, we would select every fifth plot tallied for measurement. As each plot is selected, its center is pin-pricked through the hole in the templet, circled, and numbered in red pencil. The classification of each selected plot is recorded or shown on the photo by a convenient symbol.

Each plot is assigned a volume based on three simple photo measurements:

- (1) Average total height of the dominant stand.<sup>5/</sup>  
Measured by means of a parallax wedge.<sup>6/</sup>
- (2) Average crown diameter of the dominant stand.  
Measured by means of the crown diameter scale.<sup>7/</sup>

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<sup>5/</sup> The term "dominant" has been used to designate the over-story in stands of two or more levels commonly found in Central States hardwoods.

<sup>6/</sup> Earl J. Rogers. Use of the parallax wedge in measuring tree heights on vertical aerial photographs. Northeastern Forest Expt. Sta. Forest Survey Note 1. 1946.

<sup>7/</sup> Chester E. Jensen. Dot-type scale for measuring tree-crown diameters on aerial photographs. Central States Forest Expt. Sta. Note 48. 1948.

- (3) Percent crown coverage of the dominant stand.  
Measured by means of the crown density scale. 8/ 2/

No effort is made to estimate diameter, number of logs, or even count the number of trees on the acre. Instead, gross per-acre volume is read directly from an aerial volume table 10/ and assigned to the plot. Although the measurement of a plot on photos requires more time than does a simple stereo-classification, experienced interpreters have little difficulty in measuring 50 plots per day.

Photo plots are large (1 acre instead of the 1/5 acre commonly used in ground surveys) and per-acre volumes read from an aerial table are actually averages based on several plots with similar photo measurements. The variation in plot volumes can therefore be expected to be less than that obtained on the usual field survey and the required total number of measured plots correspondingly smaller for a given degree of statistical accuracy.

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8/ Karl E. Moessner. Crown density scale for photo interpreters. Central States Forest Expt. Sta. Note 52. 1949.

9/ Average total height, average crown diameter, and the proportion of the acre covered by crowns of the dominant stand were the variables used in constructing the aerial volume tables.

10/ Moessner, Brunson, and Jensen. Aerial volume tables for hardwood stands in the Central States.

### Total Volume Estimates

Computations for photo estimates are simple. Since each plot covers 1 acre, the mean per-acre volume for a given classification is obtained from a simple average of the volumes assigned to the plots in that classification. This per-acre average multiplied by the area of the class gives the volume for that class. Volumes for all classes are summed to give total volume for the tract.

Computations are facilitated by the use of 3- x 5-inch plot record cards, on which stand measurements, volume estimates, and classifications are recorded by the photo interpreter during his study of the plot (fig. 4).

| PHOTO     |                           | PLOT      |       | Co.     | F. PLOT    |     |                 |     | AREA  | S.T. |
|-----------|---------------------------|-----------|-------|---------|------------|-----|-----------------|-----|-------|------|
| SAW       | PCLE                      | SEED-SAPS | 4     | NONFCR. | PHOTO SITE |     |                 |     | 1- 4  |      |
| TBR.      | TBR.                      | 1-STORY   |       | FIELD   | U-1        | L-2 | F-3             | B-4 | 5-14  |      |
| 2         | 3                         | 2-STORY   |       | OTHER   |            |     |                 |     | 15-40 |      |
| Av. HT.   | Av. CROWN WIDTH DOM. TREE |           |       |         |            |     |                 |     | 40+   |      |
| DOM. TREE | 0-9                       | 10-14     | 15-19 | 20-24   | 25-29      | 30+ | % CROWN DENSITY |     |       |      |
| 0 - 19'   |                           |           |       |         | VOLUME     |     | 0 - 9           |     |       |      |
| 20 - 29'  |                           |           |       |         | Cu         |     | 10 - 19         |     |       |      |
| 30 - 39'  |                           |           |       |         | Bf         |     | 20 - 29         |     |       |      |
| 40 - 49'  |                           |           |       |         |            |     | 30 - 39         |     |       |      |
| 50 - 59'  |                           |           |       |         |            |     | 40 - 49         |     |       |      |
| 60 - 69'  |                           |           |       |         |            |     | 50 - 59         |     |       |      |
| 70 - 79'  |                           |           |       |         |            |     | 60 - 69         |     |       |      |
| 80 - 89'  |                           |           |       |         |            |     | 70 - 79         |     |       |      |
| 90 - 99'  |                           |           |       |         |            |     | 80 - 89         |     |       |      |
| 100-109'  |                           |           |       |         |            |     | 90 - 99         |     |       |      |
| 110-119'  |                           |           |       |         |            |     | P.I.            |     |       |      |

Figure 4.--Photo measurements and plot volumes are recorded on 3- x 5-inch photo-interpretation cards.



Figure 5.--Annotated photo-map reproduced as a photostat showing streams, trails, roads, tract boundaries, and sites for which profiles were drawn.

#### Cruise Report Maps

Since the area and volume measurements are made directly on contact prints, type-maps are unnecessary. However, certain maps may be desirable to illustrate forest statistics in a report or to furnish a basis for future forest management. These may be produced at low cost as photo-maps (fig. 5) consisting of semicontrolled mosaics<sup>11</sup> or single photographs, annotated and reproduced as photostats. They may show tract and major forest or watershed boundaries, land lines and survey corners, stream and road networks, and primary types, sites, or other forest classification in the detail specified by the forest manager. These features may be left out if the objectives of the survey do not justify their inclusion.

<sup>11</sup> Semicontrolled mosaics--mosaics in which photos are joined by matching detail with a limited amount of control such as might be furnished by matching duplicate points on a map.

## TESTS OF THE SYSTEM

During the past five years we have used this technique of aerial estimating on a number of tracts varying in size from 40 acres to 50,000 acres. Unfortunately, field cruises were available for comparison with the aerial estimate in only a few cases. However, in almost every case tested, the aerial volume did not vary significantly from the volume obtained by normal field survey methods.

When photo and field estimates are compared, the plots tested are usually taken over a wide area. Many foresters assume that the excellent results obtained on photo estimates are due almost entirely to compensating errors which would not occur on a small area. They reason, therefore, that reliable photo cruising is impossible on small tracts.

The following tests have been selected for this publication because we believe they indicate that aerial estimating is possible on small tracts, as well as large. In addition, on these areas, the photo estimate is compared with a 100-percent field cruise or with two or more field estimates.

### Paint Creek Test

An initial test of the technique was made on tracts A and B, two adjoining 40-acre areas on the Paint Creek Experimental Forest, Allamakee County, Iowa. Personnel assigned to the forest had cruised the tracts by normal field methods. These cruises, listed below, were available for our experiment.

- a. One-hundred-percent field cruises for both tracts A and B.
- b. A sample-plot cruise consisting of 35 equally spaced 1/5-acre sample plots for tract A only.

Our objective was to test the possibilities of aerial cruising. However, because present cruising methods were not then crystalized, the cruises did not always follow the procedures advocated in this paper.

The outlines of the tract and the centers of the 35 plots located on tract A were first plotted on standard 1:20,000 scale Department of Agriculture aerial photos. Three photo interpreters then made independent estimates of the board-foot volume on tract A. Their procedure consisted of estimating average total height, average crown diameter, and percent crown coverage of the stand on the acre surrounding each of the 35 plot centers. From these

measurements and an aerial volume table<sup>12/</sup> each interpreter estimated plot volumes and then determined mean per-acre volume for the 40-acre tract. None of the interpreters had ever been on the tract and they did not see the volumes from the field cruises until after their estimates were completed. These photo and field estimates of tract A are compared in the following tabulation.

| <u>Type of cruise</u>                       | <u>Mean per-acre volume</u><br>(Bd. ft.) | <u>Difference from</u><br><u>100-percent cruise</u> |           |
|---------------------------------------------|------------------------------------------|-----------------------------------------------------|-----------|
|                                             |                                          | (Bd. ft.)                                           | (Percent) |
| 100-percent field cruise                    | 6487 ± 0                                 | 0                                                   | 0         |
| 35 1/5-acre plots measured<br>on the ground | 6241 ± 628                               | -246                                                | -3.8      |
| 35 1-acre plots measured<br>on photos by    |                                          |                                                     |           |
| Photo interpreter #1                        | 6111 ± 228                               | -376                                                | -5.7      |
| Photo interpreter #2                        | 6837 ± 213                               | +350                                                | +5.4      |
| Photo interpreter #3                        | 6537 ± 207                               | + 50                                                | +0.8      |

The photo estimates do not differ significantly from the field estimate nor from the 100-percent field cruise. Statistical analysis indicated that the number of photo plots could have been reduced from 35 to 5 without exceeding a sampling error of 10 percent at one standard deviation.

One of the photo interpreters then estimated both tract A and tract B using a procedure which combined area classification with a minimum number of measured photo plots. The area was stratified into four sites identified on aerial photos by their topographic location. These sites consisted of the ridge tops, the south or dry slopes, the north or moist slopes, and the ravine bottoms.

A transparent dot templet was laid over one photo of the stereo-pair and taped in place. The photos were then oriented for stereo-viewing and the dots were tallied by topographic site. Proportions based on this tally were then used to distribute the tract acreage by site. A single acre plot, considered by the interpreter to be typical of the site, was measured and its volume read from the aerial table. This per-acre volume multiplied by the acres in the site gave the volume for that site. The sum of site

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<sup>12/</sup> The aerial volume table used was prepared from Forest Survey plot data taken in Illinois and included volume in sound trees only.

volumes divided by the acres in the tract resulted in a mean per-acre volume for the forty. In the following tabulation these mean per-acre volumes from the stratified photo estimates are compared with mean per-acre volumes from the 100-percent field cruises.

|                 | <u>Mean per-acre volume</u>        |                                  | <u>Difference in means</u>                     |      |
|-----------------|------------------------------------|----------------------------------|------------------------------------------------|------|
|                 | <u>Photo estimate</u><br>(Bd. ft.) | <u>Field cruise</u><br>(Bd. ft.) | <u>Photo from field</u><br>(Bd. ft.) (Percent) |      |
| 40-acre tract A | 6090                               | 6487                             | -397                                           | -6.2 |
| 40-acre tract B | 7510                               | 7650                             | -140                                           | -1.8 |

Although the interpreter had the advantage of a previous estimate on tract A, he did not know the per-acre volume from the 100-percent cruise of tract B until he had completed his estimate.

By stratifying the area, the interpreter was able to estimate over-all volume from four photo plots with results almost as good as those obtained from 35 measured field plots.

In many locations measurements of so few photo plots would not result in a mean volume so close to that obtained from a 100-percent field cruise. From the viewpoint of a photo interpreter the stands on these forties were consistent, with the exception of minor differences separated by site stratification. And quite obviously the aerial volume table used represented the area, even though compiled from data taken many miles away. But we think that this test indicates quite clearly that if aerial cruises depend upon compensating errors, then at least we can expect the errors to compensate on a relatively small area.

Detailed man-hour records for the field work on a single forty are not available. However, the following tabulation compares conservative estimates of the time involved with time needed to make a photo survey.

|                                  |   |               |
|----------------------------------|---|---------------|
| 100-percent field estimate       | = | 120 man-hours |
| 35-plot field estimate           | = | 32 man-hours  |
| 35-plot photo estimate           | = | 8 man-hours   |
| 4-plot stratified photo estimate | = | 1.5 man-hours |

#### Clarke State Forest Test

A second test of the technique was made on the Clarke State Forest in southern Indiana. The 640-acre tract selected for study had been cruised many times with conventional field methods by students from the forestry summer camp, Purdue University. Volume summaries from one 20-percent cruise and from seventeen 5-percent cruises could be obtained for comparison with the photo estimates.

A trained photo interpreter made a board-foot volume estimate of the tract using standard 1:20,000 scale Department of Agriculture photos. He first stratified the area into two sites<sup>13/</sup> using a dot count. He next estimated the volume on each of 56 plots by means of an aerial volume table adjusted to southern Indiana. From these data he computed a mean volume for the tract.

The following tabulation compares this estimate with that obtained by a 20-percent ground cruise which had as its base 640 1/5-acre plots measured by forestry students from Purdue University. The cruises were put on a comparable basis by converting mean per-acre volumes to net board feet per acre, International 1/4-inch rule.

|            | <u>Mean per-acre volume,</u> |                | <u>Difference in means</u> |           |
|------------|------------------------------|----------------|----------------------------|-----------|
|            | <u>Field</u>                 | <u>Photo</u>   | <u>Photo from field</u>    |           |
|            | (Bd. ft.)                    | (Bd. ft.)      | (Bd. ft.)                  | (Percent) |
| Net volume | 2660 $\pm$ 53                | 2720 $\pm$ 180 | +60                        | +2.3      |

Although the aerial cruiser had no knowledge of the field volume before he made his estimate, the results are very close, the mean per-acre volumes do not differ significantly, and one estimate of over-all net volume may be said to be as good as the other.

Two additional photo interpreters then made independent estimates of the same tract using identical procedures. No significant difference was found between the mean volumes determined by the three interpreters nor between their volumes and that determined by the 20-percent field cruise.

The seventeen 5-percent field estimates were next averaged; this mean did not differ significantly either from the 20-percent cruise nor from the three photo estimates. However, we wished to secure some measure of the variation in over-all volumes to be expected from the two techniques. Since the photo estimates were remeasurements of 56 identical plots, and the field cruises were 17 independent samples of the same area, we compared the standard errors of the means as shown in the following tabulation:

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<sup>13/</sup> Topographic sites used were (1) dry--ridge tops and south-facing slopes, and (2) moist--north-facing slopes and ravine bottoms.

|                    | <u>Size of sample</u>                       | <u>Range of<br/>the standard<br/>errors<br/>(Percent)</u> | <u>Mean of<br/>the standard<br/>errors<br/>(Percent)</u> |
|--------------------|---------------------------------------------|-----------------------------------------------------------|----------------------------------------------------------|
| 3 photo estimates  | Based upon<br>56 1-acre plots <sup>1/</sup> | 6.6 to 6.8                                                | 6.7                                                      |
| 17 field estimates | Based upon 16<br>40-acre means              | 6.1 to 12.9                                               | 9.4                                                      |

<sup>1/</sup> Plot volumes read from an aerial table are averages of many field plots and can therefore be compared to means of field surveys.

Any one of the photo estimates had a standard error nearly as good as the best 5-percent field estimate and considerably better than the average of all field estimates.

For this particular 640-acre tract the best photo estimate was as good as the 20-percent field estimate and more reliable than the results obtained from the seventeen 5-percent estimates.

Again the cost differential is important. Photo measurements for a single estimate required less than 8 man-hours. Field measurements for the single 20-percent estimate took at least 160 man-hours.

#### Jonesboro Ranger District Test

A third test of the method was made on the Jonesboro Ranger District, Shawnee National Forest, Illinois. In this test we compared the mean per-acre volume determined from a series of photo plots with that determined from the same plots located in the field and with a mean determined from a second series of field plots located in the same Ranger District.

Photo measurements were made on thirty-seven 1-acre plots randomly selected on the government land within the district, and the volume for each plot was read from an aerial volume table compiled from Forest Survey data for Illinois.

The plots were then located in the field and measurements were made by Forest Survey crews on the 1/5-acre at the center of each of the 37 plots. From these measurements a comparable field volume was computed.

Finally, field measurements were made on 25 additional plots randomly drawn from 251 plots which had been located on every eighth forty of government land in the district. The measurements were made by Forest Service personnel assigned to the district.

From each series of plots a mean per-acre volume was computed. These means together with their standard errors are tabulated below.

| <u>Type of survey</u>                                                               | <u>Mean per-acre volume</u><br>(Board feet) |
|-------------------------------------------------------------------------------------|---------------------------------------------|
| 37 1-acre plots measured on photos                                                  | 5251 $\pm$ 391                              |
| 37 concentric 1/5-acre plots measured in the field by Forest Survey field crews     | 4973 $\pm$ 515                              |
| 25 1/5-acre plots measured in the field by Forest Service ranger district personnel | 5786 $\pm$ 605                              |

Once more the mean per-acre volume determined from photo measurements does not differ significantly from those obtained from field measurements. The photo mean lies between the two field means and must be considered as good an estimate as that obtained by either field procedure.

Again costs are important. The photo estimate was made in 8 man-hours in an office. The field estimates required approximately 40 to 60 man-hours each--much of the time spent traveling from one plot to the next.

#### LIMITATIONS OF THE METHOD

The foregoing examples include tests made on tracts of 40 acres, of 640 acres, and of several thousand acres, yet in no case were the over-all photo volume estimates significantly different from estimates made in the field. We believe this indicates that dependable over-all volumes can be obtained by measuring aerial photos without ground work, regardless of the size of the tract.

However, at present pure aerial estimating has several very definite limitations which we shall discuss below. As fast as possible we are developing procedures which may eliminate or at least get around these difficulties, but we cannot offer proof in this paper as to their reliability.

The chief limitation of aerial estimating is the inability of the photo interpreter to get precise data for individual trees directly from his aerial photos. For example, on the commonly used panchromatic photos he can recognize only a few species and often cannot differentiate between hardwoods and conifers. On photos of the scale economically feasible for aerial cruising, he cannot directly measure diameter, log lengths, or growth, nor can he expect to recognize cull trees. Even the aerial volume tables, though designed to furnish a workable short cut to over-all volumes, are limited to average situations and cannot reflect volume extremes

caused by local conditions. Obviously, with such limitations he cannot hope to get net volume by species or diameter class from his photos alone.

In spite of these limitations the requirements of many reconnaissance surveys can be met by reasonably accurate over-all volumes.

Where the objectives of the survey warrant the added cost, the aerial estimate can often be improved and elaborated by using a few selected field plots. Experiments indicate that a limited field sample can be used to adjust aerial volumes for cull and other local conditions not reflected in the averages of the aerial volume tables. These adjusted volumes use both the photo and field data and tend to be more accurate than either. Data from these field plots can also be used to distribute aerial volumes by species, diameter, and other classifications not readily recognized on photos. This same stratified field sample can furnish basic data on growth, age, and quality. Details, such as the number of field plots needed, the technique of adjusting volumes, the method of distributing those volumes, and the accuracy of the results, are now being studied. Since it now appears that a few field plots will be required on most surveys, this must be considered a limitation of the present aerial method.

Aerial estimating is limited to a certain extent by the photos available. It is not always possible to get medium-scale aerial photographs, taken recently and when trees were in foliage. Modified infra-red photos, so valuable in some regions, are not always available. However, the experiments reported in this paper were made on run-of-the-mill, panchromatic, 1:20,000 scale Department of Agriculture prints available to anyone in this country. Somewhat less accurate aerial estimates have been made on 1:30,000 and 1:40,000 prints using this technique. In our opinion, foresters need not wait for perfect photos nor for research to devise new methods of identifying species on them before securing the practical benefits of aerial estimating.

Another limitation of aerial estimating is topographic distortion. Where elevation changes of 1,000 feet or more occur on a single aerial photo, acreages determined by plot count on contact prints may be biased. This is particularly true if certain forest classes always occur on the mountain tops or in bottoms. The same distortions are present in field type-maps traced from aerial photos but may be largely eliminated in later, more precise map compilations. Throughout most of the Central States, as well as much of the rest of the country, topographic changes of this size are infrequent. Where distortion errors are known to be significant, aerial volume estimates can be adjusted by a special procedure.<sup>14/</sup>

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<sup>14/</sup> R. C. Wilson. The relief displacement factor in forest area estimates by dot templates on aerial photographs. Photogrammetric Engineering 15: 225-236. 1949.

### CONCLUSIONS

1. The sampling method described in this paper will furnish reliable area and gross volume estimates without additional forest mapping.
2. Reliable per-acre gross volume estimates can be determined from aerial photo measurements alone, without costly ground work.
3. The method is usable on small surveys of less than 640 acres as well as on state-wide inventories and results in over-all volumes as reliable as those secured by much more costly ground procedures.
4. Where maps are needed by the forest manager, they can be prepared in the detail required without affecting the accuracy or the cost of the aerial volume estimates.
5. The method is limited in its use since the interpreter cannot precisely measure individual trees, estimate cull, nor identify individual species on the available photos.
6. Adjustment of over-all aerial volumes for cull, and distribution by species or diameter classes is possible by means of limited field samples and may offer the best approach to more detailed aerial estimating.

## APPENDIX

For the benefit of the technician, we have outlined below the procedure followed on a sample aerial survey.

### Objective

To cruise the area by measuring air photos with an intensity to give a gross board-foot volume estimate with a statistical accuracy within  $\pm 10$  percent.

### Description of the Tract (fig. 6)

Experimental Tract, Jackson County, Indiana.



Figure 6.--Tract to be estimated showing boundary lines and locations of measured plots. Classifications used are large saw timber,  $\triangle$  small saw timber,  $\square$  poles,  $\diamond$  seedling-sapling.

Area--318 acres; 58 percent forest.

Stands--Pin oak, sweetgum, beech, maple, and other swamp hardwoods.

Topography--Bottomland, glacial lake origin; poorly drained deep soil.

#### Photographs

Panchromatic photos, 1:20,000 scale, flown in 1949 were available for this area. Semimatte contact prints of typical Department of Agriculture quality were used in the work.

#### Cruising Plan Followed

Boundaries of the tract were posted in red pencil on one photo of a stereo-pair.

A dot-counting templet having 64 dots to 1 square inch was oriented over one photo and taped to it. The photos were then set up for stereo-viewing.

Dots were counted and classified by forest or nonforest and by stand size class. The exact number of plots that must be counted for any given degree of accuracy of area determination can be determined by referring to a fiducial chart (fig. 7). On small surveys it is usually advisable to use a standard templet of 64 to 100 dots per square inch even though the accuracy may be less than the desired standard.

A predetermined number<sup>15/</sup> of the dots counted in each classification were selected as centers of the plots to be measured on photos. These centers were pin-pricked through the counting templet as the count progressed, and their classification was recorded. The acre plot surrounding this center was measured under stereo, and these stand measurements were recorded on 3- x 5-inch plot-interpretation cards (fig. 4). Using these measurements of total height, crown diameter, and crown coverage, the per-acre volumes were read from an aerial volume table and recorded on the same cards.

The cards were then sorted by classification and mean per-acre volumes and the errors of these volumes were determined for each classification. Although not used in computing volume, mean stand

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<sup>15/</sup> The number of plots to be measured was determined by a formula considering the volume and variability of the stand (see page 22). On small surveys it may be desirable to first classify the area and then select plots to be measured. On larger areas an estimate of the proportion in each class is used in the computation so that plots to be measured can be selected during the dot count.

CURVES FOR VARIOUS FIDUCIAL PROBABILITIES  
AT .05 LEVEL OF SIGNIFICANCE

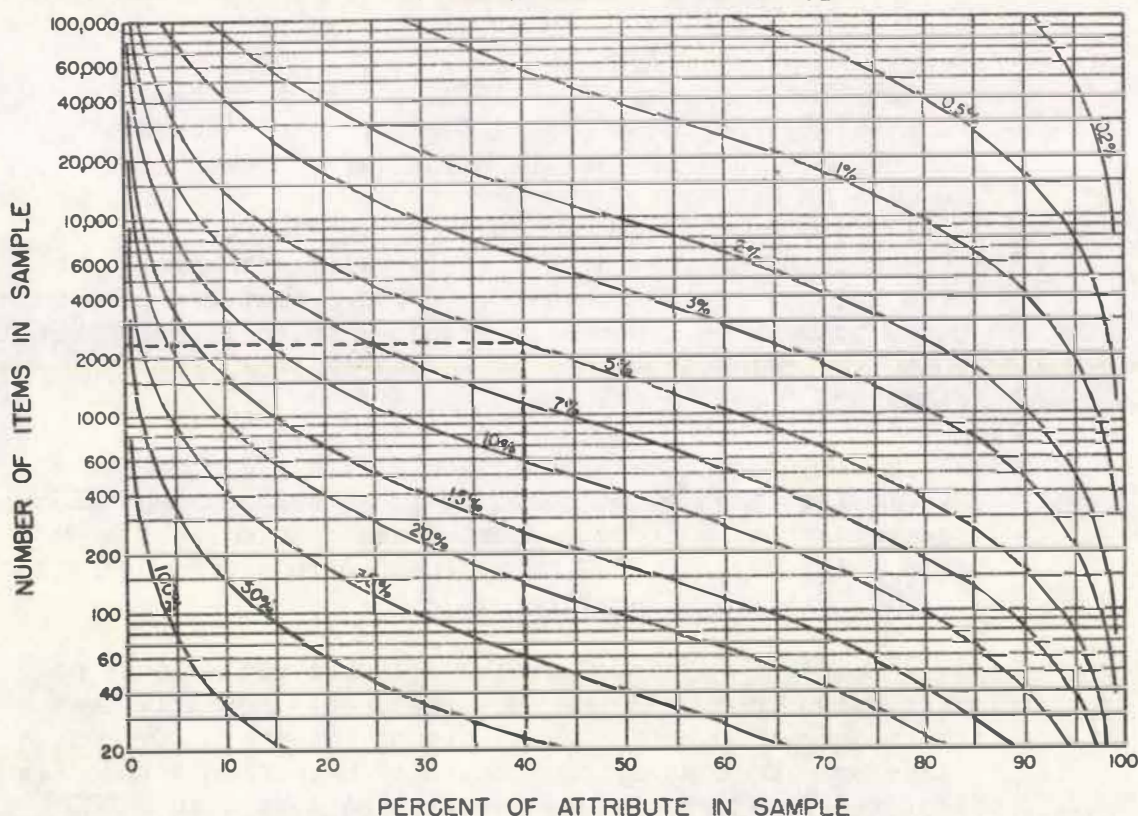


Figure 7.--Fiducial chart for determining the number of plots to be counted. For example, if 40 percent of the total area is believed to be in saw timber, and a statistical accuracy of 5 percent is desired for this class, about 2,400 plots must be counted. Because the number of plots counted can be based on only one classification, the most important classification is usually chosen. (Curves developed by the Northeastern Forest Experiment Station.)

measurements (height, crown diameter, crown coverage) were also computed as an indication of the character of the stands. Gross acreage for the tract was computed using the perimeter measurements scaled from the aerial photo. The acreage for each classification was determined by applying to this gross acreage percentages based on the original dot count.

Gross volume for each classification was then computed as a product of the acreage and the mean volume of each classification. Finally, the class volumes were summed to give the total gross volume for the entire tract.

### Classifications used in the estimate

Forest area--Areas with at least 10 percent forest crown cover, more than 120 feet wide, and more than 1 acre in area.

Large saw timber--Areas of at least 1 acre with gross per-acre volumes of 10,000 board feet or more. Normally stands more than 80 feet in height with crowns 25 feet or more in diameter.

Small saw timber--Areas of at least 1 acre with gross per-acre volumes of less than 10,000 board feet but more than 2,000 board feet. Normally stands with total height of 50 to 75 feet, with crowns averaging 15 to 25 feet in diameter.

Pole timber--Areas of at least 1 acre with gross per-acre volume less than 2,000 board feet and with at least 30 percent stocking of pole-sized trees. Normally stands with total height of 30 to 60 feet, with crowns averaging 10 to 15 feet in diameter.

Seedling-sapling--Areas of at least 1 acre with stands not qualifying in any of the above classes. Normally less than 30 feet in height, with crowns less than 10 feet in diameter. Volume, if present, will be confined to a few isolated saw-timber trees and will be less than 2,000 board feet per acre.

### Estimate of the number of plots to be measured

The number of plots to be measured within any classification is based upon the mean per-acre volume, its variability, and the desired statistical accuracy. Where the variability can be determined in advance for a given volume range, this problem can be reduced to one of substituting into a simple formula the area of the class and a factor representing its volume range and variability.

Since 1-acre plots are measured on aerial photos, we can determine the number of photo plots required to get a  $\pm 10$  percent accuracy in aerial volumes by substituting in the following formula:

$$N = \frac{100 \times \text{area} \times f}{\text{area} + 100 \times f}$$

In this formula, f is a predetermined timber-stand factor representing the variability of per-acre volumes determined by photogrammetric methods for stands having the photo characteristics of the one we are measuring.<sup>16/</sup>

From the dot count we have 67 acres of large saw timber, 64 of small saw timber, a total of 131 acres. Based upon previous study, we can assume a photo timber-stand factor of 0.18 for large saw timber and one of 0.14 for small saw timber.

Substituting in the formula for  $\pm 10$  percent accuracy we have:

$$\text{For large saw timber } N = \frac{100 \times 67 \times .18}{67 + 100 \times .18} = 14 \text{ plots}$$

$$\text{For small saw timber } N = \frac{100 \times 64 \times .14}{64 + 100 \times .14} = 12 \text{ plots}$$

The remaining 54 acres of forest area are estimated to have less than 2,000 board feet per acre gross volume. The timber-stand factor for this range of volume is assumed to be 1.31. Since the volume is so small, the estimate of this classification will have little bearing on the error of the tract as a whole. An error of  $\pm 30$  percent will be close enough and the formula used is:

$$N = \frac{10 \times \text{area} \times f}{\text{area} + 10 \times f}$$

$$N = \frac{10 \times 54 \times 1.31}{54 + 10 \times 1.31} = 10 \text{ plots}$$

The following tabulation lists the number of dots counted, the ratio used, and number of plots measured in each size class.

| <u>Classification</u> | <u>Dots Counted</u> | <u>Plots measured on photos</u> |          |
|-----------------------|---------------------|---------------------------------|----------|
|                       |                     | (Ratio)                         | (Number) |
| Large saw timber      | 69                  | 1:5                             | 14       |
| Small saw timber      | 66                  | 1:6                             | 11       |
| Pole timber           | 34                  | 1:6                             | 6        |
| Seedling-sapling      | <u>24</u>           | 1:6                             | <u>4</u> |
| Total                 | 193                 |                                 | 35       |

<sup>16/</sup> The photo timber-stand factors used were based on a study of the variability in 300 1-acre plots whose volumes were determined from photo measurements and an aerial volume table. The method used in computing timber-stand factors and the general formula for any given degree of accuracy is given by: F. D. Brunson and C. E. Jensen. Controlling the accuracy of an aerial-photo timber cruise. Central States Forest Expt. Sta. Note 66. December 1951.

### Photo Measurements Used in the Estimate

Stand measurements were made under stereo on the aerial photos for each selected acre plot. The measurements were:

1. Average total height of the dominant stand. Measured by means of the parallax wedge.
2. Average crown diameter of the dominant stand. Measured by means of the crown diameter scale.
3. Percent crown coverage of the dominant stand. Measured by means of the crown density scale.

### Volume Tables

Using the above measurements, per-acre gross volumes were read from an aerial volume table which had been previously adjusted to Indiana stands.

### Tables

The results of the estimate are summarized in the following tables:

Table 1.--Forest and nonforest area, experimental tract, Jackson County, Indiana

| Classification | Dot Count  | Percent   | Acres             |
|----------------|------------|-----------|-------------------|
| Forest         | 193        | 58        | 185               |
| Nonforest      | <u>140</u> | <u>42</u> | <u>133</u>        |
| Total          | 333        | 100       | 318 <sup>1/</sup> |

<sup>1/</sup> Total area computed from photo measurements of the tract boundaries.

Table 2.--Forest area by stand size class

| Classification   | Dot Count | Percent   | Acres     |
|------------------|-----------|-----------|-----------|
| Large saw timber | 69        | 36        | 67        |
| Small saw timber | 66        | 34        | 64        |
| Pole timber      | 34        | 18        | 32        |
| Seedling-sapling | <u>24</u> | <u>12</u> | <u>22</u> |
| All classes      | 193       | 100       | 185       |

Table 3.--Mean stand measurements and volumes by stand size class

| Classification   | Total<br>height | Crown<br>diameter | Crown<br>coverage | Gross<br>volume<br>per acre | Measured<br>plots |
|------------------|-----------------|-------------------|-------------------|-----------------------------|-------------------|
|                  | Feet            | Feet              | Percent           | Bd. ft.                     | Number            |
| Large saw timber | 100             | 31                | 75                | 22,300                      | 14                |
| Small saw timber | 75              | 22                | 45                | 6,100                       | 11                |
| Pole timber      | 50              | 15                | 80                | 1,200 <sup>1/</sup>         | 6                 |
| Seedling-sapling | 16              | 8                 | 50                | 250 <sup>1/</sup>           | 4                 |
| Average          | --              | --                | --                | 10,424                      | --                |

<sup>1/</sup> Volume in scattered saw-timber-size trees.

Table 4.--Gross volume by stand size class

| Classification   | Volumes    |         |
|------------------|------------|---------|
|                  | M. bd. ft. | Percent |
| Large saw timber | 1,494.1    | 77.5    |
| Small saw timber | 390.4      | 20.2    |
| Pole timber      | 38.4       | 2.0     |
| Seedling-sapling | 5.5        | .3      |
| All classes      | 1,928.4    | 100.0   |

Table 5.--Cost of the survey in man-hours

| Operation                 | Man-hours |
|---------------------------|-----------|
| Preparation of photos     | 1         |
| Dot count, plot selection | 4         |
| Plot measurement          | 3         |
| Computations and writing  | 16        |
| Total                     | 24        |

Table 6.--Sampling errors for the forest area and gross volume for each classification used in the survey<sup>1/</sup>

| Classification   | Total area |          | Total saw-timber volume |                         |
|------------------|------------|----------|-------------------------|-------------------------|
|                  | Acres      | Percent  | M bd. ft.               | Percent                 |
| Large saw timber | $\pm 7$    | $\pm 10$ | $\pm 141$               | $\pm 9.5$               |
| Small saw timber | $\pm 7$    | $\pm 11$ | $\pm 32$                | $\pm 8.2$               |
| Pole timber      | $\pm 5$    | $\pm 16$ | $\pm 13$                | $\pm 33.8$              |
| Seedling-sapling | $\pm 4$    | $\pm 18$ | $\pm 3$                 | $\pm 54.5$              |
| All classes      | $\pm 8$    | $\pm 4$  | $\pm 145$               | $\pm 7.5$ <sup>2/</sup> |

<sup>1/</sup> At one standard deviation; that is, 2 times out of 3, if the survey were repeated, the errors would not exceed those shown in the table.

<sup>2/</sup> If the total 35 measured plots were used to determine one mean volume per acre for the forested area, the standard error would be approximately 17 percent. That error is reduced from 17 percent to 7.5 by means of the photo stratification.

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